Evaluation of the costs and benefits of interventions to reduce indoor air pollution

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Worldwide, more than three billion people cook with wood, coal and other solid fuels on open fires or traditional stoves, contributing to more than 1.5 million deaths annually and a multitude of negative economic and environmental impacts. The aim of this article is to present the costs and benefits of interventions to reduce indoor air pollution by halving the global population currently lacking access to (1) cleaner fuels (liquefied petroleum gas (LPG)) and (2) cleaner-burning and more efficient stoves. Results are presented for 11 world subregions. Annual costs and benefits of the two interventions are modelled from 2005 until 2015. Intervention costs include fuel, stove, and programme costs, from which monetary fuel cost savings are subtracted to estimate net costs. Economic benefits include less expenditure on health care, health-related productivity gains, fuel collection and cooking time savings, and environmental impacts. Globally, annual economic benefits of halving the population without access to LPG amount to (US)$ 91 billion at a net cost of $ 13 billion. The improved stove intervention generates $ 105 billion in economic benefits at a negative net cost of $ 34 billion. The resulting benefit–cost ratios (BCR) for both interventions are favourable. The BCR for LPG ranges from 1.5 to 21.2 in rural areas, and from 2.6 to negative in urban areas. The BCR for improved stoves is negative in all sub-regions, as fuel cost savings exceed intervention costs, thus giving net negative costs. Investments in interventions to reduce indoor air pollution are potentially cost-beneficial.

1. Introduction

Worldwide, more than three billion people cook with wood, dung, coal and other solid fuels on open fires or traditional stoves [Rehfuess et al., 2006; Smith et al., 2004]. The resulting indoor air pollution (IAP) is responsible for more than 1.5 million deaths annually due to respiratory diseases – mostly of young children and their mothers [Bruce et al., 2000; Bruce et al., 2006; Smith et al., 2000a; Smith et al., 2004]. Effective solutions to reduce levels of IAP and improve health do exist. They include cleaner and more efficient fuels, improved stoves that burn solid fuels more efficiently and more completely, and better ventilation. To be effective and sustainable in the long term these solutions must be accompanied by behaviour change. In addition to improving health and reducing illness-related expenditures, interventions to reduce IAP have many impacts that, at the household level, improve family livelihoods and, at the population level, stimulate development and contribute to environmental sustainability [Bruce et al., 2000; Habermehl, 1999; Larson and Rosen, 2002; WHO, 2006].

Economic evaluation is a recognised analytical tool for comparing the costs and impacts of one intervention with those of another. Cost–benefit analysis (CBA) is one form of economic evaluation that takes into account the major economic costs and benefits expressed in monetary units, and assessed from a societal perspective [Drummond et al., 1997; Mishan, 1975]. CBA measures the net welfare effect on society of a defined intervention or mix of interventions.

Cost–effectiveness analysis (CEA) is the other major form of economic evaluation that compares the economic costs with the benefits expressed in “natural” units. The units expressed are particular to a specific sector; for the case of health interventions, health benefits are expressed in units such as health episodes, deaths, or disability-adjusted life-years averted [Drummond et al., 1997; Gold et al., 1996; Tan-Torres Edejer et al., 2003]. Both CBA and CEA can assist public policy-makers in deciding how best to allocate funds between competing projects or programmes.

Economic evaluation techniques such as CBA and CEA can thus play an important role in guiding public policy-making and investments in interventions. Previously, the World Health Organization (WHO) has presented CEA

Table 1. WHO epidemiological sub-regions

Region[1]	Mortality stratum[2]	Countries
AFR	D	Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome And Principe, Senegal, Seychelles, Sierra Leone, Togo
	E	Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
AMR	B	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela
	D	Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru
EMR	B	Bahrain, Cyprus, Iran (Islamic Republic of), Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates
	D	Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen
EUR	B	Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Slovakia, Tajikistan, The Former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Uzbekistan, Yugoslavia
	C	Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine
SEAR	B	Indonesia, Sri Lanka, Thailand
	D	Bangladesh, Bhutan, Democratic People's Republic of Korea, India, Maldives, Myanmar, Nepal
WPR	B	Cambodia, China, Cook Islands, Fiji, Kiribati, Lao People's Democratic Republic, Malaysia, Marshall Islands, Micronesia (Federated States of), Mongolia, Nauru, Niue, Palau, Papua New Guinea, Philippines, Republic of Korea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Viet Nam

Notes

1. AFR = Africa Region; AMR = Region of the Americas; EMR = Eastern Mediterranean Region; EUR = European Region; SEAR = South East Asian Region; WPR = Western Pacific Region
2. B = low adult, low child mortality; C = high adult, low child mortality; D = high adult, high child mortality; E = very high adult, high child mortality

results for interventions to reduce IAP at global and regional level in terms of cost per healthy life year gained [Mehta and Shahpar, 2004]. Until now, no global or regional cost-benefit analysis has been conducted on household energy and health interventions. Economic studies to date have focussed on stove improvements [Habermehl, 1999; 2007; Hughes et al., 2001; Smith, 1998].

The aim of this article is to present selected results from a study that applied cost-benefit analysis (CBA) to estimate the economic efficiency of selected interventions to reduce IAP at global and regional levels [Hutton et al., 2006].

2. Methods

Methods follow the WHO guidelines on conducting cost–benefit analysis of household energy and health interventions [Hutton and Rehfuess, 2006], which draw on international economic evaluation guidelines [Drummond et al., 1997; Gold et al., 1996; Tan-Torres Edejer et al., 2003]. Details of the methods are described elsewhere [Hutton et al., 2006]. All analyses were conducted for 11 developing and middle-income WHO sub-regions (see Table 1), and separately for rural and urban populations.

2.1. Interventions and scenarios modelled

Interventions were chosen on the basis of their relevance to the household energy target "to halve, by 2015, the number of people without effective access to modern cooking fuels, and to make improved cooking stoves widely available" proposed by the Millennium Project in the context of the Millennium Development Goals (MDGs) [UNMP, 2005]. Taking into account amenability to a global-level analysis, two main interventions were selected: (1) reducing exposure through changing from solid fuels to cleaner fuels; and (2) reducing exposure through a cleaner-burning and more efficient stove. Due to data constraints and the complexities of attempting to reflect different stove options in different parts of the world, a single stove option was modelled.

Costs and benefits were modelled under eight different intervention scenarios, reported in full in [Hutton et al., 2006]. Three specific interventions (liquefied petroleum gas (LPG), biofuel (ethanol) and a chimneyless rocket stove) were modelled separately at two levels of population coverage: to reduce the population not served in 2005 by 50 % or 100 % by 2015. The 50 % scenarios were further subdivided into a base-case analysis, where all users of traditional fuels are targeted equally, and a pro-poor analysis, which first targets those with the most polluting and least efficient solid fuels. This paper presents the 50 % base-case analysis. In Scenario I, this study models access to LPG as the cleaner fuel intervention, given the wider availability and current use of this fossil fuel compared to processed biofuels. In Scenario II (the improved stove intervention), a chimneyless rocket stove was chosen as a relatively cheap but functional stove that is widely used in Latin America, Africa and parts of Asia [Still et al., 2007]. No single improved stove model will

Table 2. Percentage of households using solid fuels and traditional stoves (2003)

WHO subregion	Solid fuel use (%)								Traditional stove[2]	
	Coal		Charcoal		Wood		Dung and others[1]			
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
AFR-D	2.8	0.6	16.2	4.0	28.1	41.0	31.5	49.5	92.0	98.6
AFR-E	8.8	1.6	15.1	15.0	24.6	57.9	4.4	12.1	86.6	94.3
AMR-B	0.7	3.2	0.5	2.1	3.0	46.5	0.6	0.8	91.6	75.4
AMR-D	9.6	0.1	11.7	2.2	0.7	66.8	2.8	6.2	99.8	98.0
EMR-B	0.7	0.7	0.0	0.0	0.1	0.1	18.6	51.1	89.2	89.2
EMR-D	0.4	0.5	0.5	1.1	20.8	47.8	1.2	8.8	95.3	97.5
EUR-B	0.4	0.4	0.1	0.1	4.6	31.7	0.7	1.7	36.5	13.7
EUR-C	0.9	1.1	0.2	0.4	4.9	6.0	0.2	0.0	12.4	0.9
SEAR-B	0.4	0.0	25.7	0.3	0.0	85.4	0.0	0.0	96.0	90.3
SEAR-D	3.5	1.2	7.2	1.3	16.2	71.1	1.4	16.1	95.0	93.8
WPR-B	7.1	3.3	12.4	14.3	14.6	44.5	1.2	4.6	97.8	97.6

Sources: Rehfuess et al. 2006; World Health Survey 2005 (unpublished data)

Notes

1. Others: includes agricultural residues, crop waste, grass and shrubs
2. Percentage of all solid fuel users

be able to meet the different functional and cultural requirements in all countries and settings. Characteristics of the rocket stove were used in this analysis to represent a variety of improved stove models that, in good working conditions, achieve – more or less – the impacts of a rocket stove at the approximate price of a rocket stove. Performance measures in this analysis are derived from testing of a 20 litre (l) metal can stove with a rocket-type combustion chamber [Still et al., 2007].

Costs and benefits of modelled interventions are presented on an annual basis in (US)$ for the year 2005. The analysis assumes a first year of intervention in 2006 and an intervention period of 10 years until the end of 2015. All input data were adjusted to reflect these start and end dates, based on the latest data available and, where necessary, predictions for the next 10 years. All costs and benefits occurring after 2005 were discounted to 2005 values using a discount rate of 3 %.

2.2. Population targeted

Population coverage targets are based on the world's population at the end of 2015, using UN Population Division data on expected population growth for each country. The fuel and stove coverage of additions to the population (population growth) are assumed to be equal to the starting coverage in 2005. Population coverage of fuel use and improved stove use reflect 2003 coverage [Rehfuess et al., 2006]. Given that input data for some costs and benefits are estimated at the household level, population size was converted to number of households using an average household size for each WHO subregion (see Table 2). The latter is based on weighted country-level estimates, and was calculated separately for rural and urban populations.

2.3. Costs and benefits included

The benefit-cost ratio is calculated as the annual average economic benefits of the intervention divided by the annual average economic net costs of the intervention.

Intervention costs include fuel costs, stove costs, and programme costs for the distribution of cleaner fuels or improved stoves, including related research and development investments and accompanying educational measures. Intervention costs are calculated as a net value, by subtracting from the actual costs of the intervention any monetary cost savings that occur as a result of switching away from traditional fuels or using less fuel due to efficiency gains.

Economic benefits include reduced health-related expenditure as a result of less illness, the value of assumed productivity gains resulting from less illness and fewer deaths, time savings due to the shorter time spent on fuel collection and cooking, and environmental impacts at the local and global levels. The health improvements included are those estimated as part of WHO's comparative risk assessment [Smith et al., 2004]: acute lower respiratory infections (ALRI) in children younger than 5 years; and chronic obstructive pulmonary disease (COPD) and lung cancer in women and men older than 30 years. Local environmental effects are assessed as fewer trees cut down, whereas the global environmental effects considered are reduced emissions of carbon dioxide (CO_2) and methane (CH_4).

2.4. Cost data sources and inputs

Given the global and regional nature of the analysis, sources of appropriate cost and impact data were identified to apply to these levels. Different data sources available at the global, regional and country levels were compared for relevance. For price data on traded goods available at the international level, prices were adjusted for insurance and freight using an average price multiplier available for the 11 WHO subregions [Hutton and Baltussen, 2005; Johns et al., 2002].

Whereas the features of the rocket stove will vary between contexts, a median price of $ 6 was used in the analysis, with an expected length of useful life of 3 years [Still, 2007]. Laboratory data show that the rocket stove leads to fuel savings of 34 % due to greater heat transfer efficiency [Still et al., 2007], and field data in Uganda demonstrate 55 % fuel savings [Habermehl, 2007]. The present analysis conservatively adopts the lower value of 34 %.

The study uses a cost of $ 60 for the LPG burner and $ 50 for the LPG cylinder, with an expected 10-year length of useful life, following the assumptions used in the global CEA study [Mehta and Shahpar, 2004]. Programme unit costs per stove distributed are based on published WHO data [Mehta and Shahpar, 2004], varying between $ 0.15 in SEAR-B subregion and $ 1.26 in AMR-B and EMR-B subregions.

The average consumption of different solid fuels for cooking purposes was obtained from the United Nations Statistics Division (Energy Section). Total residential LPG consumption in the 10 largest developing countries was used to reflect LPG consumption in the WHO subregions [Smith et al., 2005].

Fuel prices also vary by country and region. Fuels were categorized into those principally traded on the international market and for which international prices are available (LPG, biofuels and coal) and those largely traded domestically (charcoal and firewood). Agricultural waste products (crop residues and dung) are assumed to be collected or made by each household and thus incur no monetary cost.

According to the World LP Gas Association (WLPGA), the world price for butane (used to produce LPG) is $ 0.26/l [WLPGA, 2006]. For ethanol a near-term industry estimate of $ 0.36/l was used in the base-case analysis. Unit prices in rural areas were adjusted upwards by 20 % to reflect additional transport costs and potentially reduced competition among suppliers. For coal, the World Bank provides commodity prices for Australian export coal (a major world supplier) at $ 0.51/kg for 2005.

For biomass fuels not traded internationally – firewood and charcoal – urban and rural prices were collected both from the international literature and through contacts in selected countries. All households were assumed to purchase rather than produce their charcoal, with prices per kg varying from $ 0.13 to $ 0.77. On the other hand, 75 % of urban-dwellers and 25 % of rural dwellers were assumed to purchase wood for fuel. Fuelwood prices varied from $ 0.03 to $ 0.20 per kg.

2.5. Benefit data sources and inputs

Health impacts: For the three diseases included in the study – acute lower respiratory infection (ALRI), chronic obstructive pulmonary disease (COPD) and lung cancer – incidence and deaths attributable to indoor air pollution (IAP) were estimated for each WHO sub-region for 2002 [Smith et al., 2004]. Figures for 2005 were derived by applying the disease rates per 100,000 population in 2002 to the 2005 population figures. Postulating a complete switch from traditional fuels to cleaner fuels for all household energy uses, LPG and ethanol interventions are assumed to reduce the risk of diseases attributable to IAP to the baseline risk in the population. The assumed health impacts of improved stoves are based on three studies that have compared personal exposure levels in homes where open fires are used with homes that use improved *plancha* chimney stoves or smoke hoods, giving an average reduction in personal exposure of 35 % [Bruce et al., 2002; Bruce et al., 2004; Naeher et al., 2000]. It should be noted that combustion and ventilation conditions vary widely between different types of interventions, and these estimates should therefore be considered a poor approximation of the expected exposure reductions from a chimneyless rocket stove.

Health care cost savings: A cost saving per case of disease averted is calculated on the basis of data for each WHO subregion, disease and level of severity (i.e., treatment-seeking, unit costs of care). For an assumed proportion seeking modern health care, the cost for a typical case as an out-patient as well as the cost of hospitalization for a proportion of patients was calculated. Both are estimated for primary health facilities. Health system unit costs of out-patient and in-patient care were extracted from an international review of costs, available by WHO subregion [Mulligan et al., 2005]. Costs of disease-specific treatments, such as medicines and procedures derived from the International Drug Price Indicator Guide 2005 [MSH, 2005], were added to these unit costs. The median international price was adjusted by the WHO subregional price multipliers to take into account the costs of insurance and freight. An average length of stay for hospital in-patients was assumed for each disease and level of severity [Hutton et al., 2006], ranging from 3 to 5 days for ALRI, 8 to 10 days for COPD, and 60 days for cancer.

Productivity gains due to improved health: The human capital approach, which uses market prices from the labour market to value changes in health status, is used to value illness-free days and deaths avoided. The number of days of illness varies according to the severity of the disease and to whether the individual sought and received treatment. For example, 86 % of ALRI cases are moderate, 12 % severe and 2 % very severe [Mehnaz et al., 1997; Qazi et al., 1996; Stenberg et al., 2007], with 5, 10 and 15 days off sick when treated, respectively. For adults, the model values the economic benefits of reduced morbidity as the number of days of illness averted multiplied by the average daily gross national income (GNI) per capita in the year 2005 for each WHO subregion. For children, the number of days of illness averted is multiplied by half the average daily GNI per capita. The economic benefits of averted deaths are calculated as the annual value of time (GNI per capita) multiplied by the number of years of income-earning life lost. The latter assumes an income-earning life from the age of 15 years to 65 years. Also, on the basis of consultations with chronic respiratory disease experts, a time lag of 20 years for COPD and lung cancer was assumed as the difference between the average age at exposure and average age at disease onset.

Time savings: two types of time saving are included in the analysis – time saved in the collection or preparation of wood, dung or other biomass fuels, and time saved on cooking. Time savings are valued at the average GNI per capita for each WHO subregion. Estimates of time spent collecting wood are available in the literature [Dutta, 2005], ranging from 0.3 hours per day per household in Indonesia and Nigeria to 4 hours per day in Niger. Subregional averages for time use were estimated by taking weighted averages of values available for selected countries. For dung and crop residues, almost no published information on collection or preparation time exists; it was assumed that these fuels require half the average daily time required for collecting wood. A stove comparison study conducted by the Aprovecho Research Center provides information on the time taken to boil 5 l of water, and reports reductions in cooking time from using the rocket stove (22.3 minutes) compared with open fires (26.7 minutes) of approximately 14 % [Still et al., 2007]. Similar studies show cooking time savings of approximately 12 % from the use of propane (23.0 minutes) [Still et al., 2007]. While laboratory tests cannot be considered representative of cooking time savings in real-life, these assumptions appear very conservative in the light of GTZ reporting average cooking time savings of 1.82 hours per day in Uganda [Habermehl, 2007].

Environmental benefits: these are estimated at local and global levels. Local environmental benefits accrue as part of a switch away from biomass to cleaner fuels, or when improved and more fuel-efficient stoves lead to less consumption of biomass. Deforestation due to unsustainable firewood use can lead to soil erosion, desertification, and, in hilly areas, landslides. Rather than trying to place a value directly on these downstream effects, economic methods value instead what it would cost to avert these possible adverse effects; in other words, they estimate the cost of replacing the trees that are cut down. The replacement cost comprises the labour cost plus the cost of the tree sapling, adjusted by a wastage factor (percentage of saplings planted that do not mature). A Brazilian source estimates the average cost per tree replaced as $ 0.60 (adjusted from 1996 prices to 2005 prices) [Carneiro de Miranda, 1997].

Global environmental benefits occur when greenhouse gas (GHG) emissions are reduced. The incomplete burning of solid fuels in households leads to the emission of many different GHGs. This study focuses on CO_2 and CH_4 as these are recognised under the Kyoto Protocol. The exclusion of black carbon and other pollutants that are potentially linked to global warming gives a conservative estimate of the benefits. The global environmental value is calculated by estimating the total reduction in emissions achieved by each of the interventions modelled, based on the following.

- The amount of each fuel burnt per year, available from the study model.
- The CO_2 and CH_4 emissions for each kg of fuel burned, available from published studies [Smith et al., 2000b; Thomas et al., 2000]. For CO_2, emissions per kg of fuel burned ranged from 200 g for renewably-harvested wood and 1,688 g for non-renewably harvested wood, to 2,900 g for ethanol and 3,085 g for LPG. For CH_4, emissions per kg of fuel burned ranged from 0.054 g for LPG and ethanol, to 1 g for renewably-harvested wood and 8 g for non-renewably harvested wood, increasing to 10.53 g for dung and agricultural residues and 12 g for charcoal.
- The economic value of averting emissions of GHGs, available from the carbon trading market. A conservative trading price of $ 4 per tonne (t) of CO_2 emission reduced is used. A trading value for CH_4 was not found. However, based on the comparison of the instantaneous global warming potential between CH_4 and CO_2 for a 100-year time horizon [Smith et al., 2000b], multiplying the CO_2 carbon trading value by the 7.6 times higher potency of CH_4 gives a value of $ 30/t of methane emissions reduced[2].

2.6. Sensitivity analysis

There is considerable uncertainty in the results due to the assumptions employed in the model as well as the lack of generalizable data. Sensitivity analysis was performed to assess the impact on the benefit–cost ratio of optimistic (leading to higher benefit than the base case) and pessimistic input values. Alternative values were largely based on values available in the literature or, where these were not available, assumptions about expected ranges. Results are presented for ten sensitivity analyses: (1) changes in stove costs (LPG stove and cylinder: $ 46-150; improved biomass stove: $ 2; $ 6; $ 80) and improved stove efficiency gains (60 %; 34 %; 20 %); (2) LPG prices/l ($ 0.127; $ 0.255; $ 0.382); (3) percentage reduction in health impacts of improved stoves (60 %; 35 %; 10 %) and the lag time for the health effect in years (30; 20; 10); (4) the value of adult's time (30 % GNI per capita; GNI per capita; minimum wage); (5) the value of children's time (zero; 50 % of GNI per capita; GNI per capita); (6) savings in fuel collection and cooking times (from half the base value to 50 % higher than the base value); (7) costs of tree replacement per kg of wood collected ($ 0.00191; $ 0.005619; $ 0.019105); (8) CO_2 and CH_4 emissions per kg of fuel burned (based on ranges found in the literature [Hutton et al., 2006]); (9) the economic value of emission reductions/t CO_2 ($ 17; $ 4; $ 1); and (10) the discount rate for future costs and benefits (0 %; 3 %; 5 %).

3. Results

3.1. Costs

The annual net costs of intervention are presented in Table 3, reflecting the intervention costs minus cost savings from less fuel use. Negative figures therefore indicate a net saving associated with the scenario. The global annual cost of Scenario I – 50 % reduction in the population without access to LPG – is $ 13 billion (total costs of $ 24 billion minus savings of $ 11 billion). This compares with a net saving of over $ 34 billion for Scenario II – 50 % reduction in the population without access to improved biofuel stoves (total costs of just over $ 2 billion minus savings of $ 37 billion). Globally, 85.7 % of

Table 3. Annual net intervention costs

WHO subregion	By 2015, reduce by 50 % population without access to cleaner fuel or an improved stove					
	Scenario I: LPG (million $)		Scenario II: improved stove (million $)		Net cost per person ($)	
	Urban	Rural	Urban	Rural	Scenario I	Scenario II
AFR-D	100	840	-1090	-100	2.2	-2.8
AFR-E	-230	880	-2100	-410	1.3	-5.2
AMR-B	50	1570	-3430	-400	3.0	-7.2
AMR-D	-60	260	-1220	-50	2.2	-14.0
EMR-B	270	500	40	30	4.2	0.40
EMR-D	-30	750	-1810	-270	1.5	-4.3
EUR-B	-60	340	-1830	-40	1.2	-7.8
EUR-C	-90	120	-790	-10	0.2	-3.5
SEAR-B	-70	1520	-1220	-270	4.2	-4.4
SEAR-D	1000	3610	-4750	-80	3.2	-3.1
WPR-B	1670	200	-13630	-940	1.1	-8.5
World (non-A)	2550	10590	-31830	-2540		
World (non-A)	13140		-34370		2.1	-5.5

Table 4. Total annual economic benefits

WHO subregion	By 2015, reduce by 50 % population without access to cleaner fuel (Scenario I) or an improved stove (Scenario II)					
	Scenario I: LPG (million $)		Scenario II: improved stove (million $)		Net benefit per person ($)	
	Urban	Rural	Urban	Rural	Scenario I	Scenario II
AFR-D	2540	3080	1910	2070	13.1	9.3
AFR-E	2420	5450	2480	3850	16.1	13.0
AMR-B	610	5980	9600	7510	12.3	32.2
AMR-D	220	440	790	480	7.3	14.0
EMR-B	1330	2080	4980	2910	18.6	43.0
EMR-D	470	1620	1300	1890	4.4	6.6
EUR-B	410	1030	2130	410	6.0	10.6
EUR-C	500	410	910	70	4.1	4.4
SEAR-B	310	4030	1040	3580	12.7	13.6
SEAR-D	2610	5440	5600	4130	5.2	6.3
WPR-B	45180	4240	42970	3910	28.9	27.4
World (non-A)	56600	33800	73710	30810		
World (non-A)	90400		104520		14.4	16.7

the cleaner fuel intervention cost is accounted for by fuel costs, 13.5 % by stove costs and 0.8 % by programme costs. The global costs of the improved stove intervention are more equally divided between stove costs (56.1 %) and programme costs (43.9 %). For the cleaner fuel intervention, the net cost per person (total population as denominator) ranged from $ 0.2 in EUR-C to $ 4.2 in both EMR-B and SEAR-B.

3.2. Benefits

The total economic benefits of halving the population without access to LPG (Scenario I) amount to $ 90 billion per year. The improved stove scenario (Scenario II) generates $ 105 billion in economic benefits (Table 4).

For both scenarios savings in time required for fuel collection and cooking represent the main benefits in most subregions (Figure 1), at $ 44 billion per year out of a total $ 90 billion. At the global level, for Scenario I, health-care cost savings contribute $ 0.2 billion (0.2 %); time savings $ 45.0 billion (48.6 %); health-related productivity gains $ 40.2 billion (44.5 %); and environmental

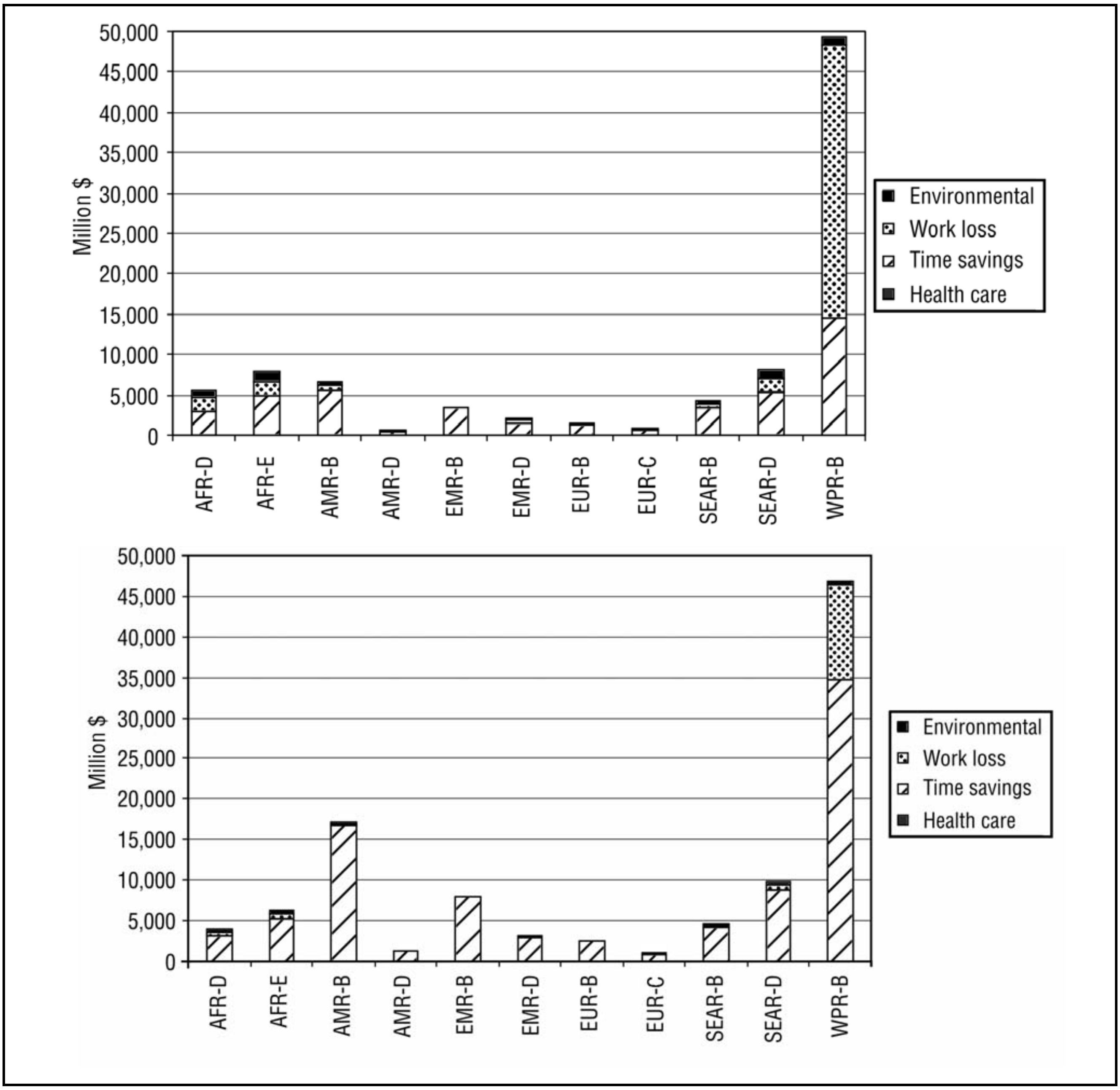

Figure 1. Contribution to economic benefits for Scenario I (liquefied petroleum gas; top) and Scenario II (improved stoves; bottom)

benefits $ 6.0 billion (6.7 %). 96 % of health-related productivity gains are related to reduced premature death, and 78 % of environmental benefits are local as opposed to global. For Scenario II, again at the global level, time savings represent the greatest single benefit (85.0 %) at $ 88 billion per year, followed by health-related productivity gains (13.6 % or $ 14 billion), environmental benefits (1.3 %, or $ 2 billion) and health-care cost savings (0.1 %, or $ 32 million). For the improved fuel intervention (Scenario II, see Table 4), the benefit per person (total population as denominator) ranged from $ 4.1 in EUR-C to $ 28.9 in WPR-B.

3.3. Benefit–cost ratios

As shown in Table 5, benefit-cost ratios vary considerably according to WHO subregion and scenario, and between rural and urban areas. For LPG, the benefit-cost ratio ranges from 1.5 in SEAR-D to 21.2 in WPR-B in rural areas, and from 2.6 to negative[3] in urban areas. For improved stoves, the benefit–cost ratio is negative in all subregions, except EMR-B where the ratio is very high at over 100. Thus, overall, the base-case results of the two interventions show very good value for money.

The wide variation between WHO subregions is the result of differences in regional characteristics and associated data inputs and assumptions, such as type of solid fuel used, economic value of time and intervention costs. A higher benefit-cost ratio can be explained both by a smaller denominator (net cost) and a larger numerator (benefit), where the former has a relatively greater impact on the benefit-cost ratio than the latter. Consequently, the divergence in benefit-cost ratios between urban and rural areas can be largely attributed to the different way in which savings in fuel cost and time influence the calculations. Fuel savings (which are higher in urban areas) are subtracted from the intervention cost in the denominator whereas time savings (which are higher in rural areas) are added to the economic benefits in the numerator.

3.4. Sensitivity analysis

Ten sensitivity analyses were performed to evaluate the impact of changes in assumptions for selected variables. Figure 2 illustrates variations for AFR-E under low and high ranges for selected input variables compared with the base-case result, as described in Section 2.6. Changes in some input value assumptions in the model affect benefit-cost ratios considerably, while others do not, as shown by the lower and upper values in Figure 2. The results were most sensitive to stove costs and efficiency, fuel prices and the value of time assigned to time savings. Globally, an alternative time value of 30 % of GNI per capita reduces the benefit-cost ratio from 6.9 to 2.2. For the other variables tested in the one- and two-way sensitivity analyses, changes observed were not major, and even under pessimistic assumptions the benefit–cost ratio remained above 5.0. In fact, within the range of all optimistic and pessimistic alternatives tested, the benefit-cost ratio always remained above 2.0.

Even with an improved stove cost of $ 80, the most pessimistic assumption for the improved stove intervention, the global net intervention costs remain negative at $ 14 billion (data not shown). It should be noted, however, that simultaneously replacing all input variables with extreme values may lead to the benefit-cost ratio falling below 1.0.

Table 5. Benefit–cost ratios for selected scenarios ($ return per $ invested)

WHO subregion	By 2015, reduce by 50 % population without access to cleaner fuel (Scenario I) or an improved stove (Scenario II)			
	Scenario I: LPG		Scenario II: improved stove	
	Urban	Rural	Urban	Rural
AFR-D	26.5	3.7	Neg.[1]	Neg.
AFR-E	Neg.	6.2	Neg.	Neg.
AMR-B	14.3	3.8	Neg.	Neg.
AMR-D	Neg.	1.8	Neg.	Neg.
EMR-B	4.9	4.2	136.1	89.9
EMR-D	Neg.	2.2	Neg.	Neg.
EUR-B	Neg.	3.0	Neg.	Neg.
EUR-C	Neg.	3.4	Neg.	Neg.
SEAR-B	Neg.	2.7	Neg.	Neg.
SEAR-D	2.6	1.5	Neg.	Neg.
WPR-B	27.0	21.2	Neg.	Neg.
World (non-A)	22.3	3.2	Neg.	Neg.
World (non-A)	6.9		Neg.	

Note

1. Neg. = negative. A negative benefit-cost ratio means that intervention cost savings exceed intervention costs. Net costs are negative.

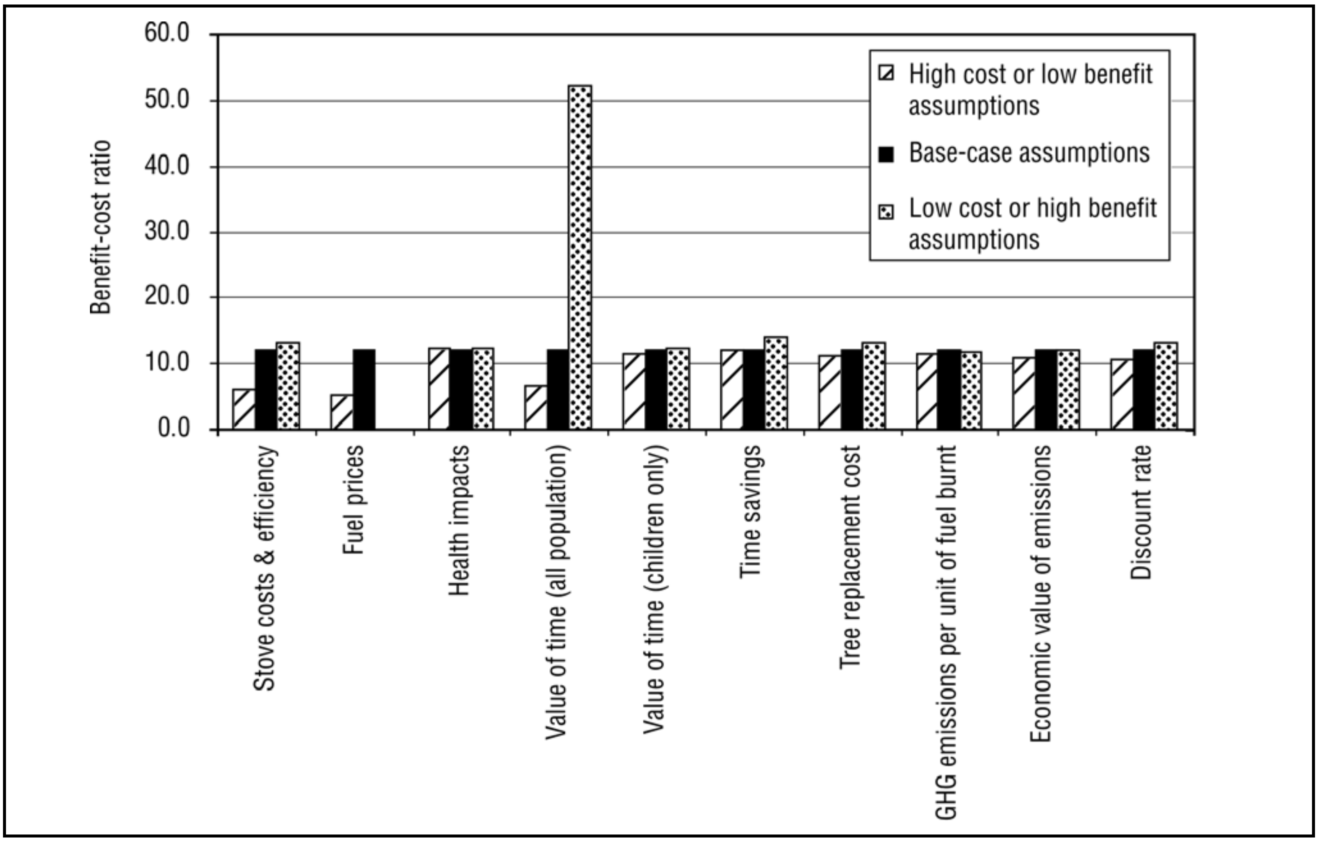

Figure 2. Benefit-cost ratios for halving the population without access to liquefied petroleum gas (Scenario I) under different assumptions for WHO subregion AFR-E. GHG = greenhouse gas. The ratio is negative and hence not shown for low cost or high benefit assumptions in the case of fuel prices.

4. Discussion

The CBA results demonstrate that interventions to reduce IAP are potentially highly efficient for society to undertake, when comparing the estimated intervention costs with a selection of major health and economic benefits. In terms of achieving the MDG target of halving the population without effective access to modern cooking fuels, the global economic benefits outweigh the costs approximately 7-fold. In other words, an annual net investment of $ 13 billion to increase access to LPG generates economic benefits worth $ 90 billion. The up-front investment is roughly $ 24 billion per year, with expected annual fuel savings of $ 11 billion. When the intervention cost saving is added to the economic benefit instead of being subtracted from the intervention cost, the global benefit-cost ratio for LPG remains high at 4.3 [Hutton et al., 2006].

In terms of halving the population without an improved cooking stove, the BCR is negative: in other words, the direct savings resulting from the intervention outweigh the intervention costs. The net intervention cost is *minus* $ 34 billion annually. The up-front investment is roughly $ 2 billion per year, with expected annual fuel savings of $ 37 billion, and generates an economic benefit of $ 105 billion. When the intervention cost saving is added to the economic benefit instead of being subtracted from the intervention cost, the global BCR is highly favourable at around 60 [Hutton et al., 2006].

This is the first global CBA of interventions to reduce IAP. Only a few country studies have been conducted, for example, in Guatemala and Kenya for reductions in mortality [Larson and Rosen, 2002] and in Pakistan for reductions in morbidity [ARCH, 2000]. These studies show that benefits outweigh costs by a factor of 10 or more.

A recent cost-effectiveness analysis (CEA) of interventions to reduce IAP was conducted for a similar set of interventions (i.e., improved stoves, kerosene and LPG) in the same 11 WHO subregions [Mehta and Shahpar, 2004]. Cost-effectiveness varies greatly by subregion for the improved stove intervention: $ 500-730 per disability-adjusted life year (DALY) averted in Africa; $ 610-1,180 per DALY averted in South-East Asia; $ 5,880 per DALY averted in AMR-B; $ 7,800 per DALY averted in EMR-D; and $ 32,240 per DALY averted in WPR-B. Cost-effectiveness ratios were less favourable for LPG interventions, ranging from $ 1,410 in WPR-B to more than $ 6,000 in other sub-regions.

Given the global nature of the study, not all of the potential costs and benefits could be included, due to lack of scientific evidence or the context-specific nature of some costs and benefits. For many input variables, in the absence of data for different countries or settings, findings from individual studies were chosen as representative at the subregional or global level.

Potential benefits of interventions to reduce IAP that were excluded comprise, for example, additional health effects for which the role of IAP as a risk factor remains inconclusive, such as tuberculosis, low birth weight and other perinatal health outcomes, and cardiovascular disease [Smith et al., 2004]; potential improvements in food safety and nutrition due to the more efficient handling of available energy sources; economic benefits of switching fuel source associated with opportunities for education and income generation; the increased availability of fertilizer when switching away from use of dung and agricultural residues for cooking and heating; the exclusion of NO_2 and other gases that are potentially linked to global warming; and the exclusion of any GHG emissions linked to charcoal manufacture.

On the other hand, some assumptions made in this study favour the interventions, such as the assumed use of a high-performing improved stove in good working condition, which provides adequately for all household energy needs and achieves constant health impacts over time. In contrast, it is more likely that stove performance declines over time due to little or no maintenance, which would also lead to lower health benefits. Furthermore, this study assumes a complete switch from traditional practices to modern practices. In reality, many households use more than one fuel or stove and will continue to do so where biomass fuels are easily available and free. In addition, interventions that free up time of those collecting fuel, especially women, may have unintended consequences, such as changing fertility patterns [Gibson and Mace, 2002].

The development impact of households moving up the energy ladder and using improved cooking stoves is clear, even in the absence of a global CBA. Yet, it is important to recognise that many barriers to successfully reducing IAP and improving household energy practices exist, including: the lack of national and state policies and leadership on household energy; apathy of governments and households and resistance to change; lack of inter-institutional coordination; lack of education and training; and household poverty and lack of access to resources [Ahmed et al., 2005]. In addition to resource constraints at the household level, there are severe resource constraints at the national and international levels, given the large number of development priorities of donors and country governments. In other words, in expanding coverage of access to cleaner fuels and improved stoves, many issues must be dealt with beyond showing that programmes to reduce IAP are a good investment. Furthermore, many challenges exist to implementing household energy programmes successfully and in a sustainable way, such as technology designs that adequately meet users' needs, quality control and financing mechanisms [McDade, 2004; Sinton et al., 2004].

Although a largely academic exercise, CBA can contribute to the policy debate and help define implementation strategies. Most importantly, CBA shows not only the potential efficiency of the interventions, but it can also point towards who is likely to incur the costs and who enjoys the benefits, according to the benefit categories evaluated in this study. We hope that this study will inspire applications of CBA at national and programme levels, using more detailed and situation-specific data. Such real-life studies will ultimately serve to better inform the design and execution of household energy and health interventions. ■

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Notes

1. The research work on which this paper is based was carried out when Guy Hutton and Fabrizio Tediosi were at the Swiss Tropical Institute. The paper was written when Hutton was at DSI Development Solutions International.
2. Editor's note: carbon trading is denominated in terms of CO$_2$-equivalent, where other GHGs are weighted by their respective global warming potential (GWP), where CO$_2$ is assigned a GWP of one. There are different values of GWP depending on the time horizon, since the atmospheric lifetimes of the different GHGs are different. A 100-year GWP is typically used. Estimates of GWPs are revised from time to time. The most recent 100-year GWP for methane is 23, though the carbon markets associated with the Kyoto Protocol use an earlier value of 21, which was the estimate at the time the protocol was signed. As of October 2007, the carbon market price in the Clean Development Mechanism of the Kyoto Protocol, applicable to developing countries, is around 12 euros (or about $ 17)/t of CO$_2$-equivalent. Since this paper is based on a WHO report, the values expressed here have not been adjusted.
3. Negative means net costs are negative, so that any further benefits would make the scenario highly favourable.

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